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The potential of big data and telecommunications in the Ebola response

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The Potential of Big Data and Telecommunications in the Ebola Response

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Abstract

Telecommunications infrastructure plays a critical role in crisis response, whether in natural disasters or health crises such as the West African Ebola response. For these latter cases, where infrastructure damage is not a problem, the crisis generates increased demands on systems already plagued by sparse coverage and limited bandwidth. Recently, the potential benefits of big data analytics has increased the demands on these networks. In turn, this generates pressure on the network operators to upgrade facilities and may present opportunities for third party support. If designed properly, these improvements may create network improvements that persist beyond the crisis.

This article examines the dampening effect of network infrastructure on data sharing and its effects for the promise of 'Big Data' as well as the role of third party organizations, namely humanitarian organizations and their private sector and donor partners, in enhancing network capacity. Through a case study of the West African Ebola response, we specify the network infrastructure limitations as well as collaborative efforts at improving infrastructure for the response and the long term.

The research sheds light on the role crisis telecommunications can play in enhancing infrastructure, building a bridge between disaster and development efforts and associated scholarship [1]–[4]. The research also provides recommendations as to mechanisms regulators might use to foster collaboration and ease the path for humanitarian organizations seeking to solve long standing network problems, even if only to meet short term needs.

Introduction

The portfolio of technologies and analytic concepts commonly referred to as Big Data have made it possible to derive ideas and actionable knowledge from large collections of heterogeneous data. When combined with ubiquitous mobile computing and extensive internet connectivity networks, such technologies are increasingly shaping everyday life with data driven decision support at both the

individual and organizational levels. However, it is unclear whether this potential can accrue to lower income nations, with more limited network and data analytic infrastructures. Despite these limitations, many have suggested data science offers a potential solution to some of the data and knowledge gaps in the recent Ebola epidemic response. However, a recent empirical investigation of the collaboration and analytic dimensions of the response effort has consistently recirculated back to discussions of connectivity. Having highlighted connectivity as a key capability for the entire response effort as well as a precursor to many of the data sharing and analytic strategies of interest to the response community, it makes sense to explore the telecommunications issues that contribute to developing connectivity in underserved or vulnerable regions such as west Africa.

This research operationalizes connectivity along its functional dimensions of coverage, bandwidth, and reliability. Combining these three components allows us to describe connectivity in realistic and meaningful ways. For instance, the coverage in a given region may be adequate, but if bandwidth is low (network speed is limited), reliability is sporadic (frequently down), or network alternatives are non-existent, then the effective connectivity for the region is still poor. As is made clear by our analysis, this detailed treatment of connectivity is necessary for assessing the role of telecommunications networks for Big Data collective analytics.

People and organizations operating in locales with poor connectivity subsequently adapt to the challenge through various workarounds depending upon which connectivity components are lacking. Poor Coverage, or Reliability might force users who rely on a connection for data collection, transfer, or general communication to work asynchronously. Bandwidth limitations on network speed generally force users to be conscious of file sizes or importance of certain communications. Subsequently, in the absence of robust connectivity, collaborators relying on network connections may need to accept less effective strategies for collecting and maintain data or communicating with peers.

This paper will contribute first by capturing and describing the current connectivity environment in West Africa through the lens of the Ebola response. This will include a discussion of both the challenges as well as the strategies for addressing those challenges. Next it will describe some ongoing collaborative efforts to develop a more stable and comprehensive connectivity environment. Both of these dynamics can be evaluated through our primary research questions regarding what types of questions and analysis are required as part of the Ebola response, and then subsequently, how data management strategies (collection, maintenance, and use/sharing) are implemented to support those needs and their associated challenges. It will conclude with a discussion of the future work toward developing connectivity in underserved regions for the purpose of supporting data driven humanitarian aid operations.

Literature Review

Emergency Telecommunications

Flexibility and resilience in the telecommunications infrastructures for information management (IM) operations, especially in the context of emergency and disaster response, is one of the most important design considerations in this application space [5]. As the disaster unfolds, response work will take many forms as will the data that enables the work. Exchanging voice calls and messages, email and text based messages, websites, and data services will all play a role in the response. Reliable multimodal information exchange is key to assuring that communication and data sharing is possible and covers the full spectrum of technical needs of response personnel. To these ends Patricelli et al. [5] propose a diversification of network technologies to be used to meet connectivity needs in disasters. A paradigm shift away from "Network Centric" operational models toward a "Network Enabled Capability" is also proposed as a more efficient and flexible alternative when reliable connectivity may be an issue. This shift deemphasizes the notion of a fused operation information infrastructure by proposing a model where telecommunication and network based capabilities are better used to coordinate action between organizations. This

promotes individual needs based adaptation rather than compliance to an apriori set of operational processes.

While models of organizational coordination enabled through connectivity are important to consider, an equally important consideration is how organizational structures and telecommunication influence the types of technology and practices adopted. Early studies regarding the potential of telemedicine to distribute physician skills from across the response community during emergency or disaster operations highlighted reliability of telecommunications networks as critical to the implementation of telemedicine [6]. While this may seem trite in the context of this paper, connectivity deficiencies resulting from poorly developed or damaged networks precludes the possibility of leveraging such an approach. Furthermore, conditions resulting in substantial risk to the reliability of the network could reduce or totally disincentivize adoption of telemedicine techniques as well as general digital data management in medical facilities on the front lines of a disaster response.

Emergency Telecommunication Technology

A number of technologies are proposed for establishing temporary networks during an emergency. Deaton et al. propose that High Altitude Platforms (HAPs) offer great potential for deploying telecommunications hardware during a disaster event [7]. These platforms position network hubs aboard aerial platforms, thus extending line of sight and/or accessing remote regions. A key caveat however is understanding the nature of network traffic in order to manage an emergency telecommunications infrastructure that relies on aerial platforms. A better understanding of network traffic typical of common disaster response scenarios would help inform better design and engineering of HAPs for emergency telecommunications.

Other emerging approaches to establishing connectivity for the purpose of communication and data collection in disaster response include mobile devices organized as an adhoc mesh network. While many

examples exist, one such approach referred to as the “explore and exploit” algorithm maximizes survivability and lifespan of a wireless adhoc network in emergency or disaster situations [8]. The algorithm addresses previous limitations of such networks by affording a means to intelligently forward network traffic through the adhoc network, considering connection and battery strength at individual nodes. This enables the network as a whole to persist as devices in the network inevitably run out of battery power and are at risk of falling offline. This approach relies on a bilateral routing algorithm for message traffic [9]. While similar solutions have been proposed before, the technology tends to suffer from performance issues limiting adoption to basic messaging. This affordance however can be of great utility if an adhoc network can be established between wireless handsets thus enabling local communication. The bilateral routing algorithm intelligently accounts for individual node information like battery strength and alternative routing in order to maximize the survivability and lifespan of the network.

Regardless of the technologies used to establish a telecommunication capacity during a disaster response, it is beneficial to consider more than just the operations at hand. Adhoc networks capable of supporting basic communication between mobile nodes only have so much utility. Drones or balloons carrying broadband repeaters help extend coverage, but only for as long as they can fly. The majority of the time extending an existing broadband architecture with ground based repeaters or very small aperture terminal (VSAT) stations is typically a more straight forward approach [4]. Reducing complexity and making use of existing network capacity also makes for a more sustainable solution that can support not just the response, but also recovery and development to stabilize the region in the future.

Maitland et al. discuss this difference between communication and information technologies as well as how they work synergistically to support disaster relief and development [2]. They explore the notion that there is a fine line between solutions designed for disaster relief and those better suited to support development, but that careful consideration of needs and available technologies can net a dual purpose telecommunications solution. Some key features of a communications technology designed for disaster

response may promote flexibility and ruggedness of the system at the cost of long term suitability in order to support development. As such, there exists a very nuanced relationship between priorities when identifying the needs for communications technologies designed initially for disaster response, but intended to serve development and reconstruction capacities as well.

Developing Country Infrastructures

A 2012 study of broadband penetration as a result of supply side and demand side policy interventions yielded a number of interesting conclusions for designing government policy to promote sustainable connectivity development [10]. First and foremost it demonstrates that policy does in fact have an impact on developing broadband penetration. From there, the authors demonstrate that while both supply and demand side interventions will have a positive effect, demand side approaches tend to be more fruitful across the big picture. With that said, another key finding is that in order to drive the development of broadband penetration effectively, a mixed portfolio of supply and demand side interventions should be used. Finally, the research indicates that the approach must be tailored to goals of policy makers and subsequently provides insight into how the impact of supply vs. demand side interventions changes as degree of broadband diffusion increases. Essentially, as broadband access becomes more ubiquitous, policy makers should shift from balanced supply/demand plans to more demand side oriented plans in order to continue to drive growth in adoption.

In a separate study of broadband diffusion in developed and developing countries, Gulati and Yates focused on key differences in governance models between developed and developing countries [11]. This perspective enabled the authors to demonstrate that certain strategies for developing connectivity penetration may work in the developing world, but be ineffective in technologically advanced nations. In general, this agrees with Belloc et al. [10] in that, as level of development and connectivity penetration increases, strategies to continue growth and adoption benefit from demand side interventions.

While the previous studies discuss incentivizing broadband network development at regional or national levels, this development can be a very geographically local issue with significant social undertones. Mariscal investigates internet penetration dynamics resulting from government investment in Mexico [12]. Amongst other things this work finds that the effects of this effort are highly skewed toward wealthy more populous areas. Differentiating between the market efficiency gap and the access gap, it is noted that though Mexico's internet penetration has generally grown, access to service remains geographically sparse. The author then suggests balanced policies that consider the social capital development resulting from government policies that balance communications and IT investment regionally, thus helping to close the digital divide.

While closing the digital divide in developing nations can be addressed by government policies that incentivize investment in broadband infrastructures, ubiquitous mobile computing and mobile broadband service offers perhaps the most attractive options for developing locales such as remote or fringe service areas [13]. By considering the cost and relative effectiveness of the mobile approach as opposed to wired and PC based models for providing internet connectivity, Loo & Ngan make the case for adoption of mobile architectures in remote or rugged regions. Many factors affect the emergence of mobile as a superior architecture, to include ease and cost of constructing the network. From the end user standpoint, mobile offers the advantage of being easier to adopt and more flexible in application. Beyond that, users in more rural or remote settings are generally better served through the adoption of mobile devices which have a much lower cost point of entry and easier and more intuitive to use.

Coverage Gaps

Whether it is the developing world or simply a rural area with limited coverage, Internet Service Providers (ISPs) make decisions about adopting new technologies and expanding connectivity based on the profit potential in those markets [3]. Given that the competition between ISPs is quite fierce, they are disinclined

to take chances on technologies that are high risk and low reward. In addition to competition from other ISPs, there exists competition from large scale telecommunications companies capable of bringing service to the end user. As a result, underserved markets tend to emerge and persist. Without some form of government policy intervention, or a dramatic event which spurs philanthropic investment, these conditions will continue.

Through the literature review we have explored some of the telecommunications issues related to setting the stage for adoption of Big Data analytics for humanitarian aid and development. Hardware, Software, and Orgware approaches to overcoming adverse environmental conditions and providing communications capacity to the region is a first critical phase. If possible, it makes a great deal of sense to consider sustainability of the solutions used in the Response phase of the disaster event, as such considerations pay dividends as Response transforms into Recovery and Development. To those ends, we explore ways to promote internet penetration and adoption of ICTs in developing locales through a balanced mixture of government policy and flexible technologies. The remainder of this paper speaks to a series of research questions in the context of the Ebola response as a case study. Those questions are as follows.

1. How does network infrastructure limit or enable the potential for Big Data analytics?
2. Where network coverage is problematic, what solutions exist?
3. How do these solutions solve both short and long term infrastructure needs?

Case Study

To understand the potential of Big Data analytics in humanitarian response, we conduct a case study of the Ebola crisis response in West Africa. This case was chosen due to its high profile nature and the many references to the potential for Big Data made in the popular press and among government officials. The

following sections outline our data collection method, interview questions and then presents the case data.

Method

The following data collection and analysis sections describe the methods of a larger study of data sharing and analytics in the Ebola response. Early in that exploratory project, telecommunications and connectivity issues were identified as a substantial component of the collaboration activities at the heart of the study. As such, a focus on understanding those limitations, and their contributing factors, became integral to understanding collaborative analytics.

Data Collection

As identified through a literature review, interview subjects included persons with positions such as data scientists, relief practitioners, data brokers, domain researchers, or a combination of these roles. Subjects were recruited from the professional network of the research team using a snowball method. The content of the qualitative interview data were triangulated against desk research and publicly available online Ebola coordination chat session transcripts. The following lists provide subject demographics and a summary of the interview guide questions as they pertain to telecommunications focus of our study.

Interview Subject Demographics

1. High level director of global humanitarian aid brokering non-profit with 20+ years experience in technology and management
2. Data Scientist and Geographer engaged with multiple prominent data analytics nonprofits from the humanitarian aid community. Has 10+ years experience in both global and field operations.
3. Executive with a prominent technology and connectivity support startup. Has 10+ years experience in government and industry.
4. Data Scientist and Medical Doctor engaged with multiple prominent non-profits from the humanitarian aid community. Has 15+ years experience in both global and field operations.
5. Professor of crisis informatics and humanitarian aid researcher with 15+ years experience
6. Professor of crisis informatics and humanitarian aid researcher with 15+ years experience.
7. Professor of crisis informatics and humanitarian aid researcher with 15+ years experience between academia and industry.
8. Professor of Communications with 15+ years experience between academia, humanitarian aid, and environmental non-profits.

9. Epidemiologist with 5+ years experience brokering spatial epidemiology support for humanitarian aid NGO's.
10. Retired Technology Professional with 5+ years volunteer service in humanitarian aid.
11. Founder of major humanitarian aid and crisis informatics non profit
12. Open source software development executive with 5 years volunteer experience in development based non-profits
13. Technology and data science executive with 5 years volunteer experience in humanitarian volunteer non-profits
14. Entrepreneur with 10+ years experience in both government and volunteer non-profits.
15. Technology and Business Manager with 5+ years experience in volunteer non-profits
16. Entrepreneur with 5+ years experience in volunteer non-profits.

Interview Guide Summary

The questions, whose answers and relevance are likely to vary with category, are formulated according to the research questions. The framework consists of five components, two reflecting the users' perspectives and three reflecting the data analytic context. Underlying the framework is an interest in multi-level governance and organizational structure, as well as the work associated with big data analyses and their use in decision making.

1. Response context - Which aspect(s) or stages of the response is your organization involved in (sensitization, treatment, logistics, etc.)?
2. Decision making process - Has your organization made use of externally sourced data in its decision making? Were these raw data or analytic outputs (maps, graphs, models)? What Types of data, sources, and formats are you most interested in? How does your organizational unit (office, work group, team) deal with uncertainty in data and statistical analyses?
3. Data availability - Are the data you need largely available? If data are collected at intervals (daily, weekly, monthly), are they reliably available?
4. Analytic techniques - What types of analyses do you use, if any, to improve the Ebola response or limit the disease spread? How do you identify the audience and how often do you interact with the intended audience of analytic products? Do they provide feedback that helps shape your work? Are there analyses you need that are not available?
5. Output format - Are the outputs of your analyses (charts, graphs, maps) configurable? If so, how?
6. Organization structure – Describe your organizational structure and hierarchy. Do you collaborate internally or with external organizations? If so, can you describe those activities in terms of purpose or nature of work?

The interviews were audio recorded with the participant's permission and semi-transcripts were developed for each interview by working significant timestamps, discussion threads, and illustrative quotes into interview notes during a secondary review. This process is reminiscent of the hermeneutic

circle used to develop more rich understanding of text through recursive reinterpretation in light of context. The process of organizing thematic discussion threads within the notes and expanding those toward semi-transcript type content also bears some resemblance to Agar's language [14] in that the thematic discussion threads are similar to strips. The difference between the method employed here and prominent applications of Agars method in other qualitative research [15] is in the role of breakdown. Instead of using breakdowns in the available coding schema to extend the schema and develop understanding of the strip meaning in an existing text, divergence or recirculation of the discussion topic in the actual interview or audio recording was used to define a new note or note thread as appropriate. Each note then has its own meaning in the context of the thematic thread it has been logged under, and each thread can be interpreted as the sum of meanings of its notes. This process represents a completely open form of interpretive reading based upon literal reading of the initial note set prior to actual code based analysis [16]. Once the final notes were developed, copies were sent to the interview subjects to perform member checking and clarification of any discrepancies.

While most of the interviews conducted were one on one between the researcher and subject, one particular interview was conducted as a group, yielding 16 subjects across 14 interviews. Table 1 summarizes the metadata for the resulting interview semi-transcripts.

Interview	Time (minutes)	Semi-transcript Pages
PS-1	48	3
PS-2	35	2
PS-3	52	4
PS-4	35	4
PS-5	23	2
PS-6	88	6
PS-7	60	5
PS-8	82	2
PS-9	70	3
PS-10	60	1

PS-11	54	1
PS-12	78	2
PS-13	75	2 + video demo
PS-14	180	5 + video demo

Table 1 : Interview Results Metadata

Ebola Response Background

Since the March 2014 inception of the Ebola virus outbreak in west Africa, upward of 30,000 human cases have been reported across five West African countries, Spain, and the US, with an estimated fatality rate of 52% [17]. Dozens of major charities, developed nations, and private corporations are engaged in efforts to provide medical assistance, logistics support, construction services, and coordination to the relief effort. From this environment an international scale data sharing infrastructure has emerged, supporting data driven decisions to the extent contextually possible. As the Ebola crisis subsides, there is a unique opportunity to study and reflect on the nature of this infrastructure, and the protracted context that defines it in order to set a stage for future discussion of technology and policies for data sharing and collaborative analytics within the humanitarian and global development community.

Under the moniker of “Digital Humanitarianism” this emerging phenomena of technologically driven social organization defines the collaboration space and activities between many humanitarian aid and disaster response actors. In the case of the Ebola response these actors included non-governmental organizations (NGO’s), certain elements of the UN, non-profits such as Doctors without Borders or NetHope, government actors from both the affected region and abroad, and finally private industry partners such as Facebook, Microsoft, and Cisco. Such a diverse community of collaborators requires connectivity, collaboration agreements between organizations, government buy-in to the activities, as well as policies and regulations to support a globally federated action network.

Connectivity Issues

In the context of humanitarian aid operations, telecommunications connectivity is an omnipresent factor affecting how practitioners communicate and coordinate work [18]. Mobile computing has become ubiquitous given its cost, value in simplicity, and integration of redundant connectivity capabilities [13]. Such technologies support both data collection and ICT functionality making them an almost necessary part of how members of affected communities, as well as response workers and host nations, work together. The following quote illustrates this importance.

“one of the things that hits home for many of us in the humanitarian world is pure connectivity”

The presence of accessible, reliable, and sustainable connectivity enables a myriad of communications methods, both synchronous and asynchronous, which can be selectively used depending on evolving needs among various stakeholders in dynamic humanitarian environments that drive the needs at hand. Opportunities to coordinate synchronously can enable the response community to be more agile and adaptive in uncertain environments. Additionally, the opportunity to share data across network connections has been shown to drive data sharing and an open data paradigm in humanitarian aid [19]. Asynchronous methods afford certain practitioners a means to selectively step away from collaborative dialog in order to focus on important tasks. Data collected in regions of conflict can also benefit from the security of offline and encrypted data collection synced to authoritative databases upon return from the field. As one practitioner noted, concerning the frequent use of Skype among those seeking to share data:

“It’s a nice collaborative infrastructure, but can almost kill you when you have a lot of crisis things going on” ... on the “Tyranny of Skype”

Connectivity can also influence the methods and strategies for doing critical work, especially in the data science domain. While it is possible and beneficial to collect data digitally, the opportunity to share data or coordinate data-centric collaboration is frequently perceived as more productive, collaborative and

efficient when the connectivity enabled technologies such as web apps and cloud storage can be used. Furthermore, in the absence of connectivity, paper and whiteboard based methods frequently find preference.

“The operational data at the district level was being collected and managed on a whiteboard, but if you don’t have connectivity, that’s what works”

Coverage

One of the key connectivity issues experienced to this day in some of the hardest hit parts of West Africa is coverage. The epidemic spread through rural and urban areas alike, spanning areas with various levels of network quality despite the urban or rural context. For example in Conakry, some humanitarian practitioners had adequate network service, enabling them to collaboratively share and update information on web-based online platforms such as GoogleFusion products. Conversely, in Freetown, similar products frequently stalled, and information sharing often was shared through box and email via asynchronous modes, with some possibilities for synchronous updating.

Coverage is also critical when operations are geographically dispersed. In such cases where data has been collected digitally, it is desirable to share that data with local collaborators or headquarters both within and between organizations. However, in the absence of any broadband connectivity, costly workarounds must be developed in order to continue sharing digital data. Sometimes the cost is in time required to coordinate a media exchange or physical transportation of the data. Other times, the cost may be in extra work to assure data integrity and consistent authoritative copies are maintained and used by communities of practice who have no choice but to rely on ad hoc data exchange schedules. A survey based analysis of Ebola response practitioners’ data management behaviors conducted by a humanitarian response organization revealed these dynamics and many others linking digital data management and analysis to connectivity access [20].

Most of these ETU's [Ebola Treatment Units] and the NGO groups were sharing things on USB drives, and manually driving USB drives to different villages to collect and share data. So anything that teams can do to help further establish Wi-Fi platforms with the intention of allowing the data teams to further share information is something that we are very interested in.

These issues can start to be addressed through a geographic analysis of existing network coverage as compared to regions where responders are operating. These underserved regions were subsequently identified by NetHope and mapping collaborators at GISCorp and Statistics Without Borders [21] to inform design of a lightweight and scalable strategy to bring needed connectivity opportunities to the region.

"There were three different map products that we updated regularly for NetHope.... and one of those was the ICT data maps. That data was a list of ICT sites from the NGOs in West Africa..... and information about their ICT needs. We would join that information to geographic data and produce maps." (that describe coverage needs)

Bandwidth

Available bandwidth for communications traffic has also presented a number of issues for Ebola response operations and personnel. One of the most impactful strategies for slowing the spread of the virus was public information campaigns emphasizing certain behavioral changes. Unfortunately, the cellphone based communication channels bogged down under the pressure of unexpected traffic.

Another way they were getting (public) messages across was through SMS and interactive voice response, so trying to send messages regarding education campaigns. The big issue with that is that these messages starting contradicting one another. For example, WHO and CDC were giving contradictory messages. Additionally, because the very limited cell phone networks within each of the countries, they broke the bandwidth.... There were just way too many messages, and so the messages were queuing for close to 4 days.

Bandwidth limitations also presented problems for response personnel operating within affected regions, frequently limiting the ability to search for basic information. The following anonymized messages from a publicly posted Ebola response coordination forum illustrate these difficulties vividly.

“Hi from Kailahun - I wonder if anyone can point to a recent ebola-related 3W map (JPG / PDF) for Sierra Leone please? With agency names (not just numbers), and ideally showing current and planned activities. Bandwidth is too limited to go browsing, so any links would be much appreciated.”

Dialog A

User 1: *We want to setup a VSAT connection in Kono (Koidu) district. Is there any information about providers in that district*

User 2: *yes we should have district level data such as this ... all available i think on hdx?*

User 3: *What organization are you with? There may already be entities operating there with bandwidth who can provide you with connectivity.*

Dialog B

User 1: *Hi, good to meet you. Would you mind please adding you details to this document. You may also find resources to assist you on the other tabs*

User 2: *Ok. Thank you. Internet here is very troublesome, so it's taking a long time to load, but I will try to do it this weekend after returning to a stronger connection, if that's okay.*

“@All, just had some feedback about field requirements for data sharing, bearing in mind that the internet connection is often not good.

- 1. Need data (rather than maps) in easily downloadable formats -csv/xls/shp;*
- 2. Consistent web addresses for updates*
- 3. 'Light' websites*
- 4. Excellent metadata, embedded rather than separate doc or on webpage”*

As illustrated, overcoming issues related to bandwidth is a pervasive problem in West Africa. Finding a workaround frequently means delaying work until a connection is available, expending extra effort to share information, and working with less than ideal data and resources.

Reliability

While bandwidth deficiencies caused problems with network based data sharing and ICT use, reliability in mobile phone networks caused similar disruptions to effective collection of data and coordination of field activities.

“One major problem - at least here in Liberia - is that data is not coming out of the ETUs outside of Monrovia. The data you are seeing reported is "word of mouth" that then finally gets down to a health district level and

there they sometimes report daily (via phone calls) and sometimes they can't get through. There are a number of reasons for this. One is connectivity/communication not working (mobile phones in rural areas are becoming unpredictable to use due to lack of call capacity)."

Returning to the discussion of bandwidth and illustrative quotes from practitioners, the tail end of this quote demonstrates the how reliability frequently depends on bandwidth.

Another way they were getting (public) messages across was through SMS and interactive voice response, so trying to send messages regarding education campaigns. The big issue with that is that these messages starting contradicting one another. For example, WHO and CDC were giving contradictory messages. Additionally, because the very limited cell phone networks within each of the countries, they broke the bandwidth.... There were just way too many messages, and so the messages were queuing for close to 4 days.

These problems of connectivity are not new and well known to those working on broadband and mobile connectivity in low income and rural contexts. Our purpose here is to highlight the limitations they create for the collection, dissemination and use of Big Data. Important to this analysis, the data volumes being discussed up to this point are not 'big.' Hence, the network infrastructure is not only creating challenges for Big Data, but for nearly any scale of data sharing.

The question that remains, and one that might be posed in any context, is 'what can be done?' In long term development contexts, government programs targeting policy or demand side stimuli, such as those discussed above may be appropriate. However, in crisis response more immediate results are required. In the following, we describe one potential solution.

Solutions

Ebola Connectivity Project Summary

To address the network issues, a consortium of key NGO and Industry partners embarked on an initiative to develop internet access for Ebola responders. Having recognized the importance of effective and reliable information transfer as part of the communication and collaboration scheme of the Ebola response, a multiphase project was headed up by NetHope. Leveraging financial and technical support from Facebook, the Paul G. Allen Family Foundation, Cisco, EveryLayer and Inveneo, the Ebola Response

Connectivity Initiative (ERCI) aims to expand high speed broadband access throughout key African countries impacted by the epidemic [22]–[24]. Table 2 outlines the key players and roles within ERCI.

Key Financiers	Hardware/Software/Orgware	Analytics
Facebook	Cisco	Facebook
NetHope	Everylayer	NetHope
Paul G. Allen Family Foundation	Inveneo	
	NetHope	

Table 2: ERCI Key Players and Roles

One of the key paradigms of ERCI is the operationally-driven collaboration between non-profit and for profit actors. While the end customers of the connectivity solution are NGOs, local organizations, and governments, and the financiers are involved for the purpose of enabling these organizations, the connectivity service itself benefits from being aligned with for-profit business models. Therefore, the solution was designed to be implemented from a non-profit perspective with cooperation from local for-profit service providers with the understanding that the extended infrastructure would be turned over to them once the epidemic is over.

“After doing NGO connectivity work and connectivity in emerging market work on the nonprofit side, we just sort of came to the realization that, connectivity is really a for profit endeavor. It's about the idea of keeping an ISP running, you have to run it like a smart and efficient business.”

The development plan for ERCI relies on a geographically weighted assessment of connectivity access and service amongst NetHope affiliated response organizations [20]. This means that responders with specified needs across the region (frequently in remote or underserved regions) were matched with the feasibility of expanding and establishing point to point wireless connections. While market forces have driven development of broadband access networks in more populated regions, the influx of response organizations, and their associated connectivity and bandwidth needs, has certainly taxed the existing infrastructure. In these cases, ERCI also aims to provide additional broadband resources to responder support networks which focus upon providing a multitude of sector base activities (logistics, health, water

sanitation, coordination) as well as logistics, data management, and communication/coordination activities [19], [22].

From a technical standpoint, the connectivity solutions leveraged as part of ERCI need to be flexible, scalable, and utilize the existing infrastructure as much as possible. As such, EveryLayer designed the architecture to augment existing regional infrastructures through a combination of extending existing service provider networks via carrier grade WiFi and reaching the most remote regions with so-called kitted satellite solutions [25].

“So the kitting, and simplicity of the kitting is so important. We have distribution kits, which are essentially sort of like a cell phone tower in terms of connectivity, in a box. There is a point to point kit which can be used in backhaul, so transmitting from point A to point B 50 km away, and then there’s the connected location, or customer kits. The way we have configured the baseline meraki and ubiquity [network and router solutions] is based on some very basic assumptions about what they are going to do with connectivity.”

The implementation was then handled by Inveneo through field teams of certified partners. In this case, Inveneo Certified Partners (ICPs) amount to local service providers trained to both install and maintain the EveryLayer connectivity solutions [26]. Through this approach, the previously mentioned financiers and planners of the initiative are able to put a connectivity solution in the hands of local service providers in a sustainable way [27]. The international partnership then has functionally subsidized the expansion of coverage, bandwidth, and reliability into the underserved markets local providers could not previously reach profitably. Additionally, the extended network developed under this initiative will be managed remotely from an operations center in Ghana, meaning maintenance of the extension should come with relatively low overhead [28]. The short term goal of bringing connectivity to the underserved region in order to support Ebola response operations is then met in a way that is feasible as well as sustainable.

The sustainability of the solution is an ancillary benefit paying dividends not just in terms of the immediate need for connectivity to support Ebola response data collection, sharing, and collaborative analytics, but also for development in underserved regions. Universal connectivity coverage has been identified as a key

communications capability needed to drive economic growth and help bolster communities against this type of disaster in the future [29].

Discussion

As evidenced by the findings of this project thus far, connectivity is a key precursor to the effective use of data technologies and appears to significantly influence adoption of data capture, storage and transmission as well as analytic methods commonly referred to as Big Data [27]. Previous research has shown that the integration of inter-organizational ICT use and Big Data or collaborative analytics is believed to hold great potential for improving humanitarian aid and disaster response operations [30]. Many opportunities to leverage analytics for data driven decision support have been identified during the Ebola response, but connectivity limitations have prevented widespread adoption of such methods.

Recognizing this deficiency, leading actors from the humanitarian NGO domain have joined with industry partners to address connectivity issues related to coverage, bandwidth, and reliability. First and foremost is bringing basic connectivity to underserved regions affected by the outbreak. Ebola Treatments Units (ETUs), contact tracing teams, and dignified burial teams operating in and throughout remote regions may not need advanced ICT capabilities, but the need to send and receive simple messages is commonplace and can make a substantial difference in the how operations are coordinated [31]. Approaches to develop network coverage during previous disasters frequently focused on the needs of the response community, considering any follow on development use of the network as a secondary priority [2]. The balance between assuring responders have a useful solution available in a timely manner, and thinking ahead toward developing an infrastructure suitable to recovery and development phases has always been tenuous. In this case, the pooling of requirements and funding for the service, combined with timing and advances in technology alleviated some of that tension, enabling a multifaceted strategy for extending the existing ISP infrastructure as well as augmenting it with VSAT capacity. This plan enjoys certain

advantages over historical implementation of VSAT technologies in that the solution was kept affordable and scalable through the use of repeaters on the existing architecture and VSAT in remote regions or where redundant connectivity options and increased bandwidth were needed [4], [27].

The sustainability of this effort hinges on a number of factors related to integrating the solution as much as possible with existing ISP architectures. Many local ISPs may be leery of investing in new technologies that complicate the management of their infrastructure and only reach a small number of new customers [3]. To work around this issue and secure buy in from local ISPs a more holistic approach was applied [27]. As previously mentioned, through the network of Inveneo Certified ICT Partners (ICIPs), the hardware solution is installed and maintained locally. The overall system is then managed by a Network Operations Center I (NOC) in Ghana [28]. The end result is a solution designed to be provided to local ISP to install and maintain as an extension of their own capacity but centrally managed from the NOC in order to reduce overhead to the ISP as part of the initiative. This model helps mitigate some of the risk ISPs might be averse to in terms of developing the network toward underserved or remote communities.

Conclusion

Through a case study of the West African Ebola response this article has examined the role of third party organizations, namely humanitarian organizations and their private sector and donor partners, in enhancing network capacity as part of a greater plan to drive innovation and adoption of increasingly advanced data collection, development, and analytic techniques commonly referred to as Big Data. Our findings highlight that, in the absence of a reliable and comprehensive connectivity network, such technologies are difficult to implement, especially in adverse conditions typical of humanitarian aid in developing countries. Based on the need for reliable internet connectivity to support effective communication, coordination, and data driven decision making, there has been intensive investment in the broadband connectivity networks of Western Africa by Humanitarian NGOs and Industry partners.

This initiative is an example of a scalable and feasible approach to integrating with local ISP architectures. Once fully implemented it will offer connectivity to the Ebola epidemic response community as well as the recovery and development efforts to soon follow.

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